Trajectory of Bearing Movement During Oxford Mobile-bearing Unicompartmental Knee Arthroplasty Using Kinematic Alignment Technique: a Retrospective Analysis

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Abstract

Background: This study was performed to clarify whether the kinematic alignment technique can improve the trajectory of the bearing movement during Oxford mobile-bearing unicompartmental knee arthroplasty (Oxford MB UKA) compared with the traditional technique using a Microplasty instrument.

Methods: We retrospectively analyzed patients who underwent UKA from January to June 2019. The kinematic alignment technique group (study group) comprised 23 patients (30 knees), and the Microplasty group (control group) comprised 25 patients (30 knees). The clinical outcomes, radiographic assessments, and intraoperative bearing movement trajectory and distance were compared between the two groups.

Results: There were no differences in the baseline characteristics or clinical outcomes between the two groups ($P > 0.05$). There were also no differences in the postoperative femoral and tibial prosthesis varus and valgus angles, femoral prosthesis flexion and extension angles, tibial slope, or prosthesis convergence angle ($P > 0.05$). The contiguity between the femoral and tibial prosthesis in the study group was 4.8 ± 1.6 mm, while that in the control group was 6.3 ± 1.8 mm ($P < 0.05$). The difference in the bearing movement trajectory was significant, with an ideal trajectory in 23/30 cases in the study group and 14/30 cases in the control group ($P < 0.05$). The bearing movement distance showed no significant difference between the groups ($P > 0.05$).

Conclusion: The prosthesis installation accuracy of the kinematic alignment technique in Oxford MB UKA was similar to that of conventional Microplasty instrumentation. However, the contiguity between the femoral and tibial prosthesis was smaller, and the bearing movement trajectory was more optimal.

Background

Dislocation of the mobile bearing is the most common reason for revisions in Asian patients who undergo Oxford mobile-bearing unicompartmental knee arthroplasty (Oxford MB UKA) [1–7], with an incidence rate as high as 7.9% [4]. Multiple studies have shown that the bearing dislocation rate is significantly higher in Asian than Western patients [2]. The mechanism of bearing dislocation is complicated. The known risk factors include a poor bearing movement trajectory, an unbalanced flexion and extension gap, impingement of residual osteophytes or cement on the mobile bearing, and a nonfunctional medial collateral ligament [1]. Malpositioning of the component results in a wider space between the margin of the bearing and the lateral wall of the tibial component, leading to a poor bearing movement trajectory and even bearing rotation. The superior surface is designed with high surrounding rims (higher in the anterior and posterior parts, lower in the medial and lateral parts). When rotation occurs, the lower rim loses its restriction to mutual movement of the bearing and femoral component, which leads to dislocation. As recommended in the Oxford UKA instructions, the ideal bearing movement is characterized by a bearing margin that maintains a 1-mm junction with the lateral wall of the tibial prosthesis throughout the whole motion of the knee. A recent study showed that the widely used

Microplasty (MP) surgical instruments could reduce the separation between the bearing and the lateral wall [8]. However, an ideal trajectory is still not achieved in more than half of cases [9].

In 2020, we introduced a kinematic alignment technique and confirmed that the prosthesis position using this method was similar to that using traditional MP devices [10]. The present study was performed to determine whether this technique can improve the bearing movement trajectory.

Methods

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of the China-Japan Friendship Hospital (approval No. 2013-SF-1). Informed consent was obtained from all individual participants included in the study.

Clinical data

We retrospectively analyzed patients who underwent Oxford MB UKA from January to June 2019. In total, 23 patients with 30 knees treated by UKA using the kinematic alignment technique were enrolled in the study group according to the surgical records. Another 25 patients with 30 knees treated by UKA using MP instrumentation during the same period were matched as controls with respect to age (± 3 years), sex, and body mass index (± 2 kg/m²). The indication for surgery was isolated anteromedial osteoarthritis of the knee with severe pain and a narrow medial joint width on X-ray examination. There was no difference in age, sex, body mass index, or follow-up time between the two groups, as shown in Table 1.

Table 1
Baseline characteristics of study group and control group

Patient Information	study group	control group	P
N	23	25	
Age (year)	67.9 $\pm$ 9.9	68.2 $\pm$ 9.2	0.930
Gender (Male/Female)	11/12	8/17	0.377
BMI (kg/m ²)	26.9 $\pm$ 4.1	26.0 $\pm$ 3.6	0.439
Follow-up (month)	27.7 $\pm$ 0.8	27.1 $\pm$ 1.7	0.184
Data are presented as n or mean $\pm$ standard deviation.			
The t-test and Fisher’s exact test were applied.			
BMI, body mass index.			

Surgical procedure

The surgeries were performed using the kinematic alignment technique introduced by Zhang et al. in 2020 [10] and were all performed by the same senior surgeon using an Oxford Phase 3 MB unicompartmental knee prosthesis. After precise resection of the tibial plateau, a feeler gauge was inserted into the flexion joint gap to confirm that the ligament tension was restored and that the relationship between the tibial plateau surface and lower limb anatomical axis was normal. Starting from the midpoint of the gauge, a vertical line was drawn on the surface of the femoral condyle with an electronic scalpel, which represented the midline of the femoral condyle. The knee joint was then fully extended, and an 8-mm gauge was inserted into the joint gap to restore the natural tension of the medial collateral ligament and correct the varus deformity. If the 8-mm gauge was still too loose, a thicker one was inserted. After the appropriate gauge was inserted, another reference line (line A) was drawn on the front surface of the femur perpendicular to the midpoint of the insertion. This line is an extremely important reference for alignment in knee extension; therefore, it was checked repeatedly, as shown in Fig. 1. The knee was flexed back to 90°, and the femoral drill guide was placed parallel to line A and located on the central line of the medial condyle. After the position of the guide was checked and fixed, 4- and 6-mm holes were drilled through the guide. A posterior condyle resection guide was inserted to remove the posterior condyle. The rest of the procedure was performed in accordance with the instructions for Oxford UKA.

Observation of movement trajectory

After balancing the flexion and extension gap, we used the method introduced by Kawaguchi et al. [9] to measure the movement trajectory of the mobile bearing. We created a set of tibial prosthesis trials with a mesh scale, which was printed vertically and horizontally at 2-mm intervals, and the first, third, fifth, seventh, and ninth lateral cells were marked in Arabic numbers to help identify the position of the bearing. With the knee in full extension and 90° of flexion, we observed the bearing position by marking the A point of the anterior midpoint and B point of the front lateral corner of the bearing trial. Therefore, the distance of the bearing movement during the knee joint flexion could be calculated, as shown in Fig. 2. The bearing moving patterns were similar to those in the report by Kawaguchi et al. [9]. The most common bearing movement patterns were as follows: (a) The distance between the bearing and the lateral wall of the tibial trial was constant and within 1 mm during knee extension. (b) During extension, the bearing moved anteriorly and gradually away from the lateral wall, and the distance between the two was more than 1 mm when the knee was fully extended. (c) The bearing moved anteriorly, starting far away from the lateral wall and moving toward the wall as the knee extended, but only two such cases were observed in the control group. (d) The bearing moved anteriorly without contacting the lateral wall, and the distance remained more than 1 mm; we observed two such cases in the experimental group and one in the control group. Because the third and fourth movement trajectory patterns were seldom seen, we defined the first pattern as an ideal trajectory and the other three as non-ideal trajectories for statistical analysis (Fig. 3).

Radiographic assessment

Anteroposterior, lateral, and full-length weight-bearing lower limb radiographs were obtained both preoperatively and within 1 week postoperatively. The accuracy of the prosthesis position was analyzed

according to the Oxford UKA instructions [11]. We measured the varus/valgus alignment of the femoral and tibial prosthesis (Fig. 4 – 1), the flexion/extension alignment of the femoral prosthesis, and the tibial posterior slope (Fig. 4 – 2). The hip–knee–ankle angle was measured on the full-length lower limb radiographs preoperatively and postoperatively. Other X-ray measurements related to the femoral and tibial prosthesis relationships were also evaluated, including the contiguity of the prosthesis (Fig. 4 – 3) and the convergence/divergence angle, which implied the axis of the femoral prosthesis relative to the surface of the tibial prosthesis (Fig. 4–4). All measurements were based on Digital Imaging and Communications in Medicine data obtained by a Picture Archiving and Communication System (Firstech, Hefei, China). The radiographic assessments were performed by two independent authors (XW S and FF L), and the interobserver and intraobserver reliabilities between the two groups were evaluated by the intraclass correlation coefficient.

Clinical outcome

The American Knee Society score (AKSS) was used to evaluate the patients' clinical outcomes and comprised two parts: the objective score (AKSS-O) and the functional score (AKSS-F), with a maximum score of 100. The average follow-up was more than 2 years. The patients' preoperative and last follow-up scores were recorded.

Statistical analysis

SPSS 25.0 software (IBM Corp., Armonk, NY, USA) was used to analyze the data. Student's t-test and Fisher's exact test were used for statistical comparisons between groups, and $P < 0.05$ was considered statistically significant. G*Power 3.1 software was used for sample size calculation, with effect size = 0.5, $\alpha = 0.05$, and power($1 - \beta$) = 0.95. The required sample size was 52 cases; therefore, we included 60 cases to account for possible loss to follow-up.

Results

There were no significant differences in age, sex distribution, body mass index, or follow-up time between the two groups, as shown in Table 1. In terms of the clinical outcome, comparison of the AKSS-O and AKSS-F showed no statistically significant differences between the two groups ($P > 0.05$). In the radiographic assessment, the intraclass correlation coefficient ranged from 0.81 to 0.92 and from 0.83 to 0.95 for interobserver and intraobserver reliability, respectively. There were no significant differences in the postoperative femoral and tibial prosthesis varus and valgus angles, femoral prosthesis flexion and extension angles, tibial slope, or convergence angle of the prosthesis ($P > 0.05$). However, the contiguity between the femoral and tibial prosthesis in the study group was 4.8 ± 1.6 mm, while that in the control group was 6.3 ± 1.8 mm; the difference was statistically significant ($P < 0.05$), as shown in Table 2. The difference in the intraoperative bearing movement trajectory was significant, with an ideal trajectory in 23/30 cases in the study group and 14/30 cases in the control group ($P < 0.05$). The bearing movement distance was 8.5 ± 3.0 mm in the study group and 8.1 ± 3.2 mm in the control group, with no significant difference ($P > 0.05$).

Table 2
Clinical outcomes, radiological assessments, and observation of intraoperative bearing movement

	study group n = 30	control group n = 30	P
Clinical Outcome			
Preoperative clinical AKSS	56.4 ± 7.2	58.2 ± 8.7	0.360
Postoperative clinical AKSS	88.6 ± 5.2	89.0 ± 4.7	0.776
Preoperative functional AKSS	48.3 ± 10.4	52.0 ± 12.6	0.224
Postoperative functional AKSS	89.3 ± 6.3	86.8 ± 6.8	0.143
Radiological assessment			
Preoperative HKAA (degrees)	172.5 ± 4.2	173.5 ± 3.8	0.334
Postoperative HKAA (degrees)	177.3 ± 2.6	177.5 ± 2.2	0.766
Postoperative Femoral angle A (degrees)	0.2 ± 3.5	0.7 ± 4.2	0.630
Postoperative Femoral angle B (degrees)	9.6 ± 2.5	9.4 ± 4.1	0.780
Postoperative Tibial angle C (degrees)	2.0 ± 2.5	1.6 ± 2.4	0.468
Postoperative Tibial angle D (degrees)	7.4 ± 1.6	8.1 ± 1.9	0.095
Postoperative Convergence/Divergence (degrees)	-1.8 ± 4.0	-0.9 ± 4.6	0.402
Postoperative Contiguity (mm)	4.8 ± 1.6	6.3 ± 1.8	0.001
Intro-operative bearing movement			
Ideal trajectory (ideal/total)	23/30	14/30	0.033
Bearing movement distance (mm)	8.5 ± 3.0	8.1 ± 3.2	0.621
Data are presented as mean ± standard deviation or n.			
Bold P-values indicate statistical significance (P < 0.05).			
AKSS, American Knee Society score; HKAA, hip–knee–ankle angle.			

Discussion

The most important finding of this study is that a higher ratio of ideal moving trajectories were observed in the study group with less contiguity of the implants on the anteroposterior knee extension X-ray. Therefore, we considered that more optimal bearing movement can be achieved with this kinematic alignment technique. The recommended movement trajectory of the mobile bearing was 1 mm away

from the lateral wall, without contact, and not substantially separated from the wall. However, multiple studies have shown that most movement patterns are characterized as follows: during the whole motion of knee extension, the bearing is parallel to the lateral wall from 90° to 60° but is more likely to become separated from the lateral wall from 60° to 0° [9, 12]. Other studies have shown that the bearing rotation is easier when the contiguity between the margin of the bearing and the wall increases, which might be one of the causes of bearing dislocation [1, 13]. Therefore, close attention has been given to methods of improving the bearing movement trajectory. Most previous studies focused on the matching and alignment of the tibial and femoral prosthesis to prevent bearing tilt and impingement on the lateral wall [12, 14–16]. However, Kawaguchi et al. [9] reported that the ratio of the optimal bearing movement was unsatisfactory, which is similar to the finding in our control group. Our kinematic alignment technique was modified from the conventional surgical technique using MP instrumentation. The tibial resection was the same as that described in the Oxford operation manual. However, determination of the femoral implant position was not performed according to the intramedullary rod and intramedullary link; instead, we used the tibial cut plane and overall alignment as references for femoral bone preparation. Therefore, this method could also be called the extramedullary technique. Our past research showed that UKA performed using this technique can be as reliable and accurate as the conventional technique in terms of the prosthesis position but that it has a shorter operating time, less blood loss, and more rapid recovery without intramedullary interruption [10]. Moreover, the results of the present study showed that this method can improve the bearing movement trajectory, which is another advantage.

The principle of this kinematic alignment technique is easy to understand. Determination of the femoral condyle midline and line A ensured that the central line of the femoral prosthesis was located on the midline of the gauge when the knee was flexed and extended. The lateral margin of the gauge was close to the lateral wall of the tibial osteotomy surface, which ensured stability of the distance between the lateral margin of the femoral component and the wall of the tibial component during knee flexion and extension. Our radiographic assessment showed less contiguity of the femoral and tibial components in the study group than in the control group, which also confirmed that the reference line A could reduce the separation of the components when the knee was extended. Koh et al. [8] reported that the introduction of MP instrumentation could reduce the contiguity from 9.6 to 6.5 mm. Our technique could further reduce the contiguity to 4.8 mm. However, if the distance between the femoral and tibial components is too small, impingement will occur, which could lead to tilting or even dislocation of the bearing [15, 17].

This technique is different from the calipered kinematic alignment technique described by Rivière et al. [18], in which the tibial cut plane is determined according to the flexion and extension axis of the medial femoral condyle. Our method is indeed a hybrid technique of both measurement resection of the tibia and kinematic alignment resection of the femur, and the goal of this technique is to increase the compliance of the position of the femoral prosthesis with the tibial resection surface. Therefore, this technique mainly depends on an accurate tibial cut, which is also very important to the bearing trajectory. If there are defects in tibial resection, especially rotational errors, the tibial component might be incorrectly chosen and positioned with potential consequences of poor bearing motion as well as mismatch between the femoral and tibial components [12, 16]. Inui et al. [15] reported that when the femoral component was too

close to the tibial lateral wall, impingement could hardly be avoided with tilting of the bearing. They also reported a case of lateral dislocation of the bearing and suggested that the mismatch of a larger femoral component with a smaller tibial component might have been the cause [17]. If the tibial resection is not ideally performed, this kinematic alignment technique is not recommended. However, the position of the tibial component can be improved by a modified keel slot preparation technique introduced by Hiranaka et al. [19], which could be used as a remedy for poor tibial osteotomy.

Theoretically, this method relies on a properly chosen feeler gauge to reconstruct the ligament tension of the knee before resection of the posterior femoral condyle. Ideally, the axis of the femoral component should be perpendicular to the surface of the tibial component, which means the convergence should be close to 0. However, our radiographic evaluation showed that this measurement in the study group was not different from that in the control group. One possible explanation is that the intraoperative medial collateral ligament tension determined by the feeler gauge might not be the same as that after implantation of the final prosthesis.

This study has two main limitations. First, the patients were followed up for an average of 2 years only, and there were no revision cases. A further study with longer follow-up is needed to clarify the difference in clinical outcomes between the two surgical techniques. Second, this was a single-center study with all procedures performed by the same senior surgeon; therefore, it was not widely representative. Multiple surgeons or even multicenter studies are needed to clarify the effectiveness of this technique.

Conclusion

This study demonstrated that the kinematic alignment technique in Oxford MB UKA provides prosthesis installation accuracy similar to that obtained with conventional MP instrumentation. However, the contiguity between the femoral and tibial prosthesis was smaller, and the bearing movement trajectory was more optimal.

Abbreviations

MB UKA, mobile-bearing unicompartmental knee arthroplasty; MP, Microplasty; AKSS, American Knee Society score; AKSS-O, objective American Knee Society score; AKSS-F, functional American Knee Society score.

Declarations

Ethics approval and consent to participate

After obtaining institutional ethics committee approval (No. 2013-SF-1), this study was conducted in the China-Japan Friendship Hospital. Written informed consent was obtained from each patient.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

All authors contributed to this study. XW S and QD Z designed the study. WS G performed all the surgeries. XW S and FF L collected and analyzed the data. XW S, FF L, LM C, and WG W wrote and revised the manuscript. All authors read and approved the final manuscript.

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Figures

Figure 1

The positioning of the femoral drill guide depended on the central line of the medial condyle in flexion and line A in extension, both of which should be started from the midpoint of the feeler gauge and perpendicular to the tibial resection surface.

Figure 2

The left figure shows the tibial trial that we created to record the bearing movement. The grids were printed vertically and horizontally with an interval of 2 mm. The first, third, fifth, seventh, and ninth small grids on the anterolateral side were marked in Arabic numbers to help identify the position of the bearing. The right figure was taken at knee flexion of 90°. The position of the bearing was recorded according to the position of points A and B.

Figure 3
 Bearing movement trajectory patterns.

Figure 4

Radiographic assessment Fig. 4-1 Angle A: femoral varus/valgus angle. Angle C: tibial varus/valgus angle. Fig. 4-2 Angle B: femoral flexion/extension angle. Angle D: tibial slope. Fig. 4-3 Contiguity between the lateral margin of the femoral component and lateral wall of the tibial component. Fig. 4-4 Convergence/divergence angle of the femoral component relative to the tibial component.